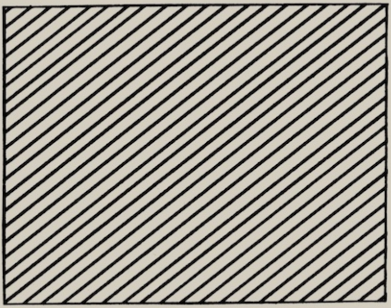
THINGS

of science



COLOR VISION

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COLOR VISION

When we view the landscape and enjoy the blue sky, the green grass and perhaps a red flower or two, we usually assume others see the same colors we do. But the blue, green or red one person observes may be very different from the color sensations another receives on looking at the same scene.

People differ greatly in the sensitivity to colors. Some see them well, some poorly and to a few, colors appear only as varying shades of gray.

The normal human eye can distinguish about a half a million different colors, but little is yet understood or known exactly how the eye does this.

The laws of physics are the basis on which colors are analyzed and the exact color specification of any surface can be determined by an instrument called the spectrophotometer, but color perception is a subjective response and varies from individual to individual. Only you know what color sensation you receive when you look at the sky, grass or flower.

The perception of color is affected by a variety of factors. By doing the experiments in this unit you will learn something about their effects and about normal

and abnormal responses to color stimulation.

First examine your materials.

PSEUDO - ISOCHROMATIC PLATE —Card with colored spots.

METAMERIC PAIR—Card on which two similar color chips are mounted.

DISTANCE TEST — Card containing four small colored circles.

COLOR CONFUSION CHARTS — Three: Protanope, Deuteranope and Tritanope.

COLORED PAPERS—Three: green, 2 x 2 inches; orange-yellow, 3 x 3 inches; orange, 2 x 3 inches.

HOW DO WE SEE COLOR?

In order to see color, we must have a light source, a reflecting surface in most cases and eyes with proper receptors to receive the stimulation.

Light is a form of energy and consists of electro-magnetic waves that travel through space in a wave motion. Its wavelengths are very short and measured in tiny units called nanometers. A nanometer is one-billionth of a meter and is abbreviated as nm.

Sunlight, our main source of light, is made up of waves of various wavelengths. You are all familiar with the rainbow of

colors produced when sunlight, passing through a triangular prism, is separated into its components. The array of colors represents the light waves that we can see, having wavelengths from about 380 to 750 nm and is referred to as the visible spectrum. Energy of wavelengths shorter and longer than these is present in sunlight, but we cannot see it. It is because sunlight has components of different wavelengths that we have object color.

The six colors of the spectrum, violet, blue, green, yellow, orange and red, may be grouped into three main divisions, blue (380 to 500 nm), green (500 to 580 nm) and red (580 to 750 nm). Any possible color can be produced by mixing various amounts of these three colors. Yellow light is produced by combining red and green lights.

Experiment 1. Note the colors of your three tinted papers. Now take them into a darkened room where little light can penetrate. Can you distinguish the colors now? Turn on the light. The colors immediately become visible again. Without light, there would be no color. You may have noticed that on a dark night unlighted trees and shrubbery appear gray.

Experiment 2. Color itself is not a property of an object, although we or-

dinarily think of it in this way. The reflection of light from the surface gives the observer the sensation of color. Color becomes evident only when light strikes a surface and the reflected waves enter a person's eyes.

When light falls on the leaves of a tree, the leaves appear green to you because the reflected light waves which give the sensation of green reach your eyes.

The third necessary element for seeing color is the eye and its ability to respond to certain wavelengths.

At the back of the eye is a membrane called the retina containing the visual receptors, the rods and cones. The rods are spindle-shaped nerve cells sensitive to small amounts of light and useful primarily for night vision.

The cones, so-called because of their cone-shape, are employed mostly for daytime vision and are the receptors that enable us to see color.

Near the center of the retina is a small yellow pigmented area called the macula lutea. At the center of the macula lutea is the fovea centralis, a very small slightly depressed area containing no rods but a great quantity of cones. The eye is most sensitive to colors at the center of the retina surrounding the fovea where the

cones are the densest. Most of the cones are grouped near the center of the retina. The rods, on the other hand, are most numerous 10 to 20 degrees from the center.

Experiment 3. Look straight ahead and focus your eyes on a particular spot. While keeping your gaze fixed on that point hold the green paper in your unit about one foot away from you at eye level, but to the side just outside your line of vision. Bring it forward slowly, moving it along a circular path.

Do you first detect a shadowy movement of an object having no particular shape at the corner of your eye? This response is due to the rods which provide us with peripheral vision, so important to us when walking or driving a car.

As you move the paper forward, it will gradually take shape and appear dark gray. As you move it further along toward the center of your visual field, the cones take over and the paper appears dark blue. When the paper is almost straight ahead, it acquires its original color. Colors are perceived most clearly when directly in front of your eyes since most of the cones are found in the center of the retina.

You can see from his experiment that the color of the paper is not a pure green but contains some blue.

Experiment 4. Hold the 2 x 3-inch orange paper about a foot in front of your eyes. Close your right eye and slowly move the paper to the right, keeping your left eye fixed at a point directly in front of you. Does the color of the paper change to a bright yellow?

Yellow objects can be detected at a wider angle than red objects. The orange paper is a mixture of red and yellow. Since red light is visible in a smaller visual angle than yellow, as the paper is moved outward, the cones respond only to the yellow light and the red color disappears. When the paper is moved further outward, it turns gray and loses its color.

Experiment 5. Yellow and blue objects can be detected at a wider angle than red or green objects. Can you devise an experiment to demonstrate this?

COMPLEMENTARY COLORS

Every color is closely related to another known as its afterimage complement. When the eye, adapted to a color on a gray background, looks at some point of the background, the complementary color appears as an after image. The color circle (Fig. 1) shows afterimage complementary colors opposite each other. Note that adaptation to yellow produces a violet

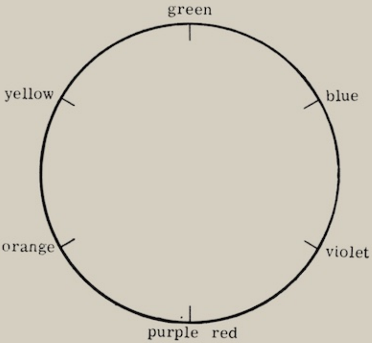

Fig. 1

afterimage and that to orange, a blue.

Experiment 6. Make a small dot in the green paper and then place it on a gray background and gaze at the spot steadily for 30 seconds or more in a bright light. Now look away from the color to the gray background. Do you see a red square?

Do the same with the 3 x 3-inch orange-yellow square. What color do you see this time? Is it blue?

If you place the green square in the center of the orange-yellow paper and repeat the experiment you will see a red square framed in blue.

The colors you observe are afterimages and are in colors complementary to the

original colors.

As you gazed at the green paper, the receptors for these wavelengths became adapted to the continuous stimulation, becoming less sensitive to the color. Therefore, when you shifted your gaze to the gray background which reflects all colors about equally, the effect was greater on the red receptors resulting in the red afterimage.

A similar response occurred after you looked steadily at the orange-yellow card. The receptors sensitive to these wavelengths became fatigued and the complement of the color appeared as a blue afterimage.

Complementary colors of any color can be produced in this manner.

Experiment 7. Look steadily at the green paper. Does it seem to acquire a grayish cast after 30 seconds or so? The effect is as if the red afterimage were superimposed on the green neutralizing the color and turning it gray.

Take the orange-yellow square and hold it at arm's length in front of you. Gaze at it steadily for about a half minute. Now bring the paper half the distance closer to your eyes. Do you see a small gray square in the center of the paper while the outer margin appears in its

original hue? When you moved the paper closer to your eyes, the orange-yellow light fell on a broader area of your retina. The cones in this area were not adapted to the paper's color while those at the center had become fatigued. The blue after-image of the smaller square neutralized the original orange-yellow color producing the gray color.

An afterimage will change in color depending on the background to which your eyes are shifted. Try this.

Experiment 8. Place the green paper on a white background and gaze at it steadily for 30 seconds or more in a strong light. Does the reddish complementary color spread over the edges onto the white paper? Does the green paper change in color?

Experiment 9. Cut two strips ½ x 1-inch in size from your orange paper and place one in the center of the orange-yellow square and the other in the center of the green square.

Does the orange color look different on the two different backgrounds? If you were successful in holding your eyes still, then this phenomenon could be called simultaneous color contrast. But if, as is usual, your fixation wavers, the phenomenon would be called successive con-

trast, resulting from adaptation of your eyes to the color of the surrounding area.

Experiment 10. Cut a ¼-inch square from opaque white paper and place it in the center of the green paper. Do the same with the orange-yellow paper. Does the white paper appear slightly different in color on the two different backgrounds?

Experiment 11. Look at the illustration on the cover of this booklet steadily. Do you see pastel colors running perpendicular to the lines? This is an example of the Prevost-Fechner-Benham subjective colors which according to one theory are due to the constant wavering of the eyes. However, visual scientists do not all agree with this theory and are still arguing about the causes of these colors.

METAMERISM

Experiment 12. Look at the color chips on your card marked "Metameric Pair" in a room illuminated by incandescent light (tungsten-filament). Do they match? Because of minor variations in color vision that may exist among individuals, the colors may not appear to be exact matches to all persons.

Now take the card outdoors and look at the colors in daylight. Do they still look alike? Note that color chip B now

appears lighter and greener. This proves that the two chips are spectrally different. A color match between spectrally different chips is called a metameric match.

Experiment 13. Note the spectrophotometric chart below the metameric pair. The dotted line is the spectrophotometric curve for color chip A and the solid line for color chip B. Note that the curves for the two colors are different. The curve for color A shows that it was formulated from one coloring material, a yellow pigment. Curve B indicates the color was formulated from a mixture of pigments (light yellow, medium yellow, red and black).

Observe that the curves cross at four points. In order for colors to be metameric the curves must cross at least three times in the visible spectrum.

When colors are compared purely by visual responses, or physiological means, the instrument used is a colorimeter.

Metameric matches are colorimetric, rather than spectrophotometric, physiological rather than physical.

This experiment demonstrates one reason why it is so difficult to match colors. You probably have had the experience of selecting at a store a piece of ribbon or spool of thread to match blue or green

material, only to find on returning home, that they did not match at all. It is one of the main concerns of textile manufacturers to create colors that can be spectrally matched with various types of materials and so remain a match under different lighting.

For a match to be nonmetameric, the curves must be virtually identical. Therefore, color matchers use spectrophotometers rather than colorimeters when a nonmetameric match is required.

Experiment 14. If the metameric pair do not match exactly for you, increase the distance from your eyes. Do you reach a point where the colors look exactly alike?

When pairs are strongly metameric, the accuracy of the match is affected by the distance at which they are observed. At close range the maximum variation may be experienced.

The macular pigment in the central 5 degrees or so of the retina acts as a yellow filter and reveals the unstable character of the complex color.

Experiment 15. Ask a number of your friends to look at the metameric pair in both daylight and artificial light. They may differ in their reactions to it. Some may say they match well and others may see differences that you do not observe.

These differences in color perception depend on variations in the make-up of each person's eyes and the pigmentation contained within the eye.

DEFECTIVE COLOR VISION

In order to match any given color only three fixed colors are necessary. If a person of normal color vision wishes to match a spot of light by using other lights of different colors, he will find he needs only three lights of different wavelengths, blue, green and red. If he wishes to match a pigment, he will need only red, yellow and blue to reproduce the exact color.

The color vision of a normal observer, therefore, is said to be trichromatic.

Partially color blind persons need only two colors to match a third—they are dichromatic. A totally color blind person is monochromatic, needing only one color for matching, since all colors look alike to him.

Persons with defective color vision therefore have less ability to discriminate colors and see many more metameric colors than a person with normal color vision.

Experiment 16. Look at your card containing various sized colored dots in diffused daylight with the light coming

over your shoulder. Place it about 2 to 3 feet in front of you with one of the long sides uppermost. Write down the number you see formed by some of the dots. You may have to switch the card around if you have placed it upside down.

Experiment 17. Try this test on your friends to see whether they see the same number you do. Do some fail to see any number at all? If so, do they have trouble identifying colors? Remember, however, that no one test, and certainly no single part of a test is sufficient to determine whether or not a person is color deficient.

The pseudo-isochromatic plate in your unit is one of the color-perception charts used for testing color deficiency, familiarly known as the "hidden digit" test. The plates were made available for use in this unit by the Beck Engraving Company, Philadelphia, Pa. The test was first issued in the United States during World War II. The original test of this type was designed by J. Stilling in Germany late in the 19th century. Later, Dr. S. Ishihara, a Japanese professor, extended this idea by constructing (1) plates showing one number to people of normal vision but another to those having certain forms of color deficiency and (2) plates that can be read by such people, but not by those having

normal vision.

The card in your unit is for detecting red-green color blindness, the most common type of color deficiency. About one man in 20 and one woman in 200 confuses red with green. Only a very few are defective in yellow-blue vision and very seldom is anyone totally color blind.

Defective color vision is usually inherited, although it may sometimes result from injury to the eyes. It is transmitted as a sex-linked characteristic. Figure 2 shows how color blindness is transmitted in general from parent to child. A female needs two defective genes for color vision to be color blind, while a male suffers from color deficiency if he has one defective gene for color vision. In Figure 2, Y represents the gene for color vision.

A female having only one defective gene is called a carrier since she is not color blind but can transmit the deficiency to her children.

Look at Figure 2 and you will find that:

Fig. 2-1. If the genes for color vision are normal in both parents, all the children will have normal color vision.

Fig. 2-2. If the father is color blind and the mother has no defective genes for color vision, all the sons will have normal

INHERITANCE OF DEFECTIVE COLOR VISION

Normal male	XY
Normal female	YY
Color blind male	XY'
Carrier female	YY'
Color blind female	Y'Y'

1

normal father	XY	
normal mother	YY	
all children normal	XY	XY
	YY	YY

2

color blind father	XY'	
normal mother	YY	
both sons normal	XY	XY
both daughters carriers	YY'	YY'

3

normal father	XY
carrier mother	YY'
normal son	XY
color blind son	XY'
normal daughter	YY
carrier daughter	YY'

4

color blind father	XY'
carrier mother	YY'
normal son	XY
color blind son	XY'
carrier daughter	YY'
color blind daughter	Y'Y'

5

normal father	XY	
color blind mother	Y'Y'	
both sons color blind	XY'	XY'
both daughters carriers	YY'	YY'

6

color blind father	XY'	
color blind mother	Y'Y'	
all children color blind	XY'	XY'
	Y'Y'	Y'Y'

Fig. 2

color vision and all the daughters will be carriers (have one defective gene for color vision).

Fig. 2-3. If the father has normal color vision and the mother is a carrier, half the sons will have normal color vision and half will be color blind, while all the daughters will have normal color vision but half of them will be carriers.

Fig. 2-4. If the father is color blind and the mother a carrier, half the sons will have normal color vision and half will be color blind, while half the daughters will be carriers and half will be color blind.

Fig. 2-5. If the father has normal color vision and the mother is color blind, all the sons will be color blind and all the daughters carriers.

Fig. 2-6. If both parents have defective color vision all the children will be color blind.

There are several types of congenital color blindness.

A dichromatic person, or one who is partially color blind, can make only two kinds of color distinction—light-dark and either yellow-blue or red-green. He may have one of three types of dichromatism: protanopia, deuteranopia or tritanopia.

Note the three charts in your unit desig-

nated "Protanope," "Deuteranope," and "Tritanope." These charts show the colors confused by the three types of dichromats.

The partly curved boundary on each of the confusion charts represents the spectrum colors (red, orange, green, blue, violet); the straight boundary, the purples, produced by mixing spectrum red with spectrum violet.

Experiment 18. Protanopia is sometimes referred to as "red blindness" because protanopes lack a red sensitive mechanism. They can see only two hues—blue and yellow. They confuse stimuli normally seen as red and bluish green with gray and with each other. All three colors are seen as gray.

Look at your color-confusion chart marked "Protanope." In this chart colors lying along the same lines are confused with each other by protanopes.

Note that turquoise, gray and red are closely along the same line. Follow the other lines and note other colors that are confused with each other. The protanope sees light of all wavelengths to which he is sensitive as some shade of blue, yellow or gray.

The most unusual characteristic of a protanope is the almost total lack of response of his visual receptors to longer

wavelengths. Beyond 650 nm in the spectrum he sees only very dim yellow instead of the normal bright red.

Experiment 19. A deuteranope is unable to distinguish purplish red and green from gray. All these colors look gray to him. On the chart marked "Deuteranope," follow the line from purplish red through gray to sea green. All colors along this line will appear gray to a deuteranope. Note the colors along the various other lines to see the other colors he confuses.

The deuteranope sees light of all wavelengths as some shade of blue, yellow or gray.

Deuteranopia is sometimes referred to as "green blindness" since deuteranopes lack a green-sensitive mechanism.

The deuteranope like the protanope can see only two hues, blue and yellow. However, note the differences in the colors confused by deuteranopes and protanopes.

The long-wavelength end of the spectrum appears darker to the protanope than to a deuteranope.

Experiment 20. The spectrum to a tritanope, or one having yellow-blue deficiency appears in only two hues, red and green. The tritanope is characterized by his inability to distinguish violet and greenish yellow from gray and, in fact,

all appear as gray.

Examine the confusion chart labeled "Tritanope." Follow the line passing near gray. Note that violet and olive green lie along this line. To a tritanope, the short-wave half of the spectrum appears green and the long-wave half red.

The retinal limits for red-green vision are more restricted than that for yellow-blue vision as you noted in Experiment 5. Therefore, the field of color sensitivity for the protanope and deuteranope, who see yellow and blue light, is greater than for the tritanope who sees red and green but not yellow and blue.

Other types of color defectiveness include total color blindness. Total color blindness is exceedingly rare. To such a person, the world appears to be painted in various shades of gray, like a black and white photograph. He sees no colors.

Anomalous trichromatism is a form of abnormal color vision in which the person needs three primaries to match any color, but his matches are different from those of a normal person.

Experiment 21. Look at your pseudo-isochromatic plate again and note the colors chosen as likely to be confused by those with red and green color deficiencies. Do they correspond with colors con-

fused in your charts for protanopes and deuteranopes?

Experiment 22. Look carefully at the stop-and-go traffic lights in your town. Are they true red and green? The signals are produced by filtering incandescent-lamp light by yellowish red and bluish green filters. Signal red plots on the boundary of the confusion chart between tangerine and red, and signal green plots close to sea green.

Use the confusion chart to see how this choice of signal red and signal green makes it easier for color defectives to distinguish them.

Signal red and caution yellow are confused by most color defectives, but as they both mean "stop," no real harm results. There is also a definite difference in the intensity of these lights, caution yellow being the more intense.

There are many fields of employment where the ability to see colors instantly and accurately is necessary. A railroad engineer, an airplane pilot, surgeons who must see tissue colors accurately and chemists who identify specimens by color need eyes that can distinguish colors correctly. Think of other types of work in which the ability for precise discrimination of color is essential.

YELLOW-BLUE DEFICIENCY

Experiment 23. Go outdoors to do this experiment. Hold the card with the four small colored circles on it about 30 feet away from a friend and ask him to name the colors. Do not let him see the colors before you do the experiment. If he cannot see the circles at this distance, have him walk toward you until they become visible as distinct spots. After he has named the colors show him the card. Did he name them correctly?

Now ask your friend to hold the card so you can see the colored circles and slowly move away from you. At what distance from you do the two pairs of colors become confused?

As the card is moved into the distance, the yellowness and blueness of the colors disappear and the dots appear only as reddish brown or as dark green. At greater distances do the colors look dark gray?

This experiment shows that although there are few tritanopes, everyone is yellow-blue blind for small or distant objects.

Look at your color confusion chart for tritanopes. Would the confused colors lie

near the same line?

Many questions about the causes of color vision and its mechanism are still unanswered and scientists are continuing their research in this field. Color vision involves not only physics but physiology and psychology as well.

If you wish to study this subject further, the references below will be helpful.

An Introduction to Color, Ralph M. Evans, John Wiley & Sons, N. Y.

Color: A Guide to Basic Facts and Concepts, Robert W. Burnham, Randall M. Hanes, C. James Bartleson, John Wiley & Sons, N. Y.

Color in Business, Science and Industry (Second Edition), Deane B. Judd and Gunter Wyszecki, John Wiley & Sons, N. Y.

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